SUMMARY: MACHINE PROTECTION ISSUES AFFECTING BEAM COMMISSIONING

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1. LIST OF PRESENTATIONS

1. Commissioning and (early) operation - view from machine protection, Jan Uythoven
2. What Systems request a Beam Dump, Jörg Wenninger
3. What is required to safely fill LHC, Verena Kain
4. What is required to get the beam safely out of LHC, Brennan Goddard
5. Beam Commissioning of the Collimation Systems, Ralph Assmann
6. Critical Beam Losses during Commissioning and Initial Operation, Guillaume Robert-Demolaize
7. Commissioning of Beam Loss Monitors, Bernd Dehning

2. COMMISSIONING AND EARLY OPERATION – WHAT SYSTEMS REQUEST A BEAM DUMP

Machine protection and collimation for LHC is very complex and a full session was therefore dedicated to its commissioning and early operation. The damage level for fast proton losses at 450 GeV is about $1\text{-}2{\cdot}10^{12}$ and at 7 TeV to about $1\text{-}2{\cdot}10^{10}$. For 7 TeV, a pilot bunch is close to the damage limit. The proton-proton luminosity operation with safe beam would be limited to some 10^{27} s^{-1} cm^{-2}.

A substantial part of the commissioning can already be done without beam during equipment tests and hardware commissioning.

As for the general beam commissioning presented in [1], commissioning of the machine protection systems will take place in stages. For protection, a stage depends on several parameters, such as momentum, beam intensity and operational states. Since the stages for general commissioning do not have the required granularity, “sub”-stages are proposed:

- first pilot with an intensity of less than 10^{10} protons
- beam with 10^{12} protons, safe at 450 GeV
- 43 bunches per beam

The commissioning stages will be different for different types of equipment. Tables are given in [2] defining what protection systems are required for each stage.

The stages and the formal acceptance of the machine protection systems should be defined, documented and approved before the tests. Corresponding procedures need to be written and agreed upon.

One risk is an uncontrolled modification of critical parameters in the protection systems, such as thresholds for beam loss monitors. Direct and uncontrolled access to front-end crates of critical systems is not acceptable. A comprehensive system to manage critical settings is required.

The creation of a Machine Protection Coordination Team is proposed, supported by many key players in machine protection. Such team should drive the formalisation of the commissioning procedures and validate tests together with operation. The team would be composed by a small team of experts, also available for consultation during commissioning and operation.

3. INJECTION AND DUMPING THE BEAMS

The damage limit at 450 GeV is ~ $2{\cdot}10^{12}$ protons (~5 % of nominal full batch). Injection protection must be in place and working correctly when the intensity of the injected beam from the SPS exceeds this limit.

Injection protection systems should be operational for 156 on 156 with $9{\cdot}10^{10}$ protons per bunch in stage I and therefore need commissioning at latest during operation with 43 on 43 bunches, to authorise starting operation with 156 bunches.

According to the overall commissioning strategy for protons, it is mandatory to have all injection protection systems fully operational for commissioning stage II (936 bunches per ring, 96 bunches maximum injected, maximum intensity per bunch: $9{\cdot}10^{10}$ protons).

Starting from extraction from the SPS, the injection protection systems that are required for the different stages are given in table in [3].

The TCLI absorbers can be commissioned later since these devices are only required above 50% of nominal injected intensity.

Extraction of high intensity beams from the SPS and transport through beam-lines with tight apertures will be commissioned before LHC beam operation. The commissioning of CNGS and TI 8 with high(er) intensity beams are foreseen for 2006. Beams for CNGS operation in 2006 have more stored energy than nominal beams for injection into LHC.

A sequencer will drive the LHC through various states to ensure safe operation. "Operational states" in the sequencer for the various sub-systems including the protection systems have to been defined (e.g. TDI "ready for pilot", TDI "ready for intermediate",..). Clearly the interplay between the various software systems such as sequencer, management of critical settings and software interlocking plays a crucial role in guaranteeing safe operation and needs to be further addressed.

The commissioning pathway for injection protection needs formalisation. For passive protection systems (beam absorbers), setting-up methods should be established.

Already for operation with pilot bunches, the LHC Beam Dumping System should be operational to safely extract the protons. No beam without a functioning beam dumping system! There are a number of safety critical aspects of the Beam Dumping System, with different levels of criticality.

In a first phase, many tests can be performed during hardware commissioning and during the reliability run that has been proposed. As an example, the interconnectivity between the subsystems and reliability assumptions will be validated.

The second phase requires careful commissioning with pilot beam:

- At 450 GeV in the LHC before extraction, to check the beam optics and aperture for the stored beam in the beam dumping elements
- At 450 GeV before first ramp, to check the beam optics and apertures at injection energy
- At 450 GeV to check the "Inject & Dump" mode
- During the ramp, to validate the energy tracking and other settings for the different beam energies
- Specific checks are required when the LHC beam parameters change (more bunches, more intensity, different bunch pattern, etc.), to verify instrument response, diagnostics and losses

Commissioning of the TCDQ/TCS positioning in IR6 can be relaxed in the case of limited β squeeze and limited number of bunches. The beam halo load on the TCDQ during "minimum collimation", see section 4, might lead to Q4 quenches. This issue needs further investigation.

The "Inject and dump mode" should be available from the start and needs to be addressed. There are still many details to be finalised: timing, data recording, diagnostics, configuration management, etc.

During stage I abort gap monitoring and cleaning could be important for operational efficiency, although this is not required for damage protection.

4. COLLIMATION

The collimation system provides several functions:

- Beam cleaning
- Passive machine protection
- Background control for the particle physics experiments

Each collimator scenario must be compatible with all three functions.

Based on recent simulation results, the full LHC collimation system of phase 1 should allow reaching 40% of nominal intensity. Taking into account machine imperfections, the cleaning efficiency could be lower by a factor between 2-5.

There is a clear view on how to commission the phase 1 collimation system with well defined priorities, based on performance studies. Commissioning will start from reduced sets of collimators and relaxed tolerances. Then collimator sub-systems will be added. If only cleaning efficiency is considered, secondary collimators could be delayed, but they will be used for the required passive protection ("safer" minimal system).

Passive protection is not as complete as with all collimators at tight settings in this approach, even with "safer" system. The early use of W collimators simplifies the system but with higher sensitivity to damage (reduced robustness).

Many collimators can initially be put in after the start of the ramp (e.g. to avoid problems during snapback), if controls and machine stability allows to do so safely.

Significant risk and uncertainties in minimal approach: Collimator production and installation must aim at a full collimator complement so that we can adequately optimize performance, passive protection and robustness.

There are ~40 collimators per ring for phase 1 of the collimation system. About 3700 Beam Loss Monitors are installed around the machine. Assuming that the beam halo is intercepted by a collimator, a limited number of BLMs at fixed locations are expected to always detect beam losses. Most of these are monitors at the collimators and downstream in the arc. The loss locations are fairly insensitive to closed orbit distortions. Some locations close to dipole magnets in the dispersion suppressor downstream of the cleaning insertion have been identified where additional BLMs should be positioned.

It should be kept in mind that all results come from computer simulations... reality will show.

5. BEAM LOSS MONITOR SYSTEM

There are several steps for the commissioning of the Beam Loss Monitor system, starting before beam operation:

- Establishing BLM thresholds to avoid quenches. A small safety factor is sufficient.
- Establishing BLM thresholds to avoid damage. A large safety factor is required. Most monitors will have thresholds that are much lower, since they are also used to prevent quenches. The threshold for protection against damage must never be excceded.
- The thresholds are loaded into the BLM controllers.
- The system is validated without beam.

The next step is after start-up LHC with beam:

- Analysis of beam losses causing beam aborts or quenches to identify/verify model uncertainties (parasitic to operation).
- Beam quench tests to optimise threshold tables (sector test will establish procedure).

In case of an excessive number of beam aborts or quenches, there must be some flexibility to change the thresholds of the beam loss monitors.

Tools for analysis of beam aborts and quenches must be available for the start-up (logging, post mortem, etc.)

There are about 4000 BLMs, and the threshold for each BLM depends on energy and on integration time. This is a very complex system, and the question was asked if we could reduce the complexity for initial operation?

6. CONCLUSIONS

It was pointed out by several speakers that settings used in the machine protection systems should be well controlled. Wrong settings could compromise the correct functioning of BLMs, collimators, and other systems. Work on the Management of Critical Settings is ongoing and a draft for functional specification has been written**. For the start-up, such a system must be in place.**

Access to equipment via the controls system will not be as easy as for other CERN accelerators in the past, due to the large risk. The separation of technical network and office network is a clear progress and the first step. **A strategy for accessing equipment via the network, from inside and outside CERN, is required.**

Machine protection systems will be required for the different operational stages. Not everything is required for day one, but most systems should become available when accelerating 156 bunches per beam. **A follow-up should ensure that the protection systems are ready when they are required**.

The commissioning of the Beam Dumping System requires other systems to be operational, such as beam monitors (BPMs, Screens, BLMs), collimators (TCDQ & TCS in IR6, other collimators). **It is important that everyone is aware and understands the implications for the Beam Dumping System**. Colleagues from several groups are concerned, RF, BI, CO, ATB, etc.

Although the calculated cleaning efficiency improved with respect to the last workshop, operation of LHC will be strongly affected by cleaning efficiency. The allowed beam intensity during operation at a certain stage will be limited to survive high loss rates without quench. An increase in the allowed beam intensity will be obtained by improving the machine (lifetime, orbit etc.) and the collimation system (more jaws, tighter gaps etc.).

There is a factor of 1000 in cleaning efficiency with respect to other machines – **we must be prepared to learn with beam**.

A simplification for the early operation is to use fewer jaws, and/or with relaxed collimator settings, then bring up the complex system in steps.

The commissioning of the collimation system must be done in a controlled way with good beam conditions. During the early operation it only requires beam loss monitors at collimators and some few other locations.

Operation of the beam cleaning system requires a powerful controls system. Collimator positions are critical and must be managed accordingly.

Sophisticated controls for the collimators are required, and software to optimise setting-up procedures.

For each operational stage, operational settings are known, **maximum allowed settings of collimators for machine protection need to be worked out in detail**.

The Beam Loss Monitor System (detectors, electronics etc.) is expected to be operational before beam. **The commissioning and operational scenarios must be further developed**.

Formalised procedures, documented and approved, for machine protection systems is required for different stages. This is successfully being done for Hardware Commissioning, **but it is important that this approach for beam commissioning is agreed upon and taken seriously**.

Operating conditions for the different commissioning stages have to be defined. Each system including the beam dumping system will be commissioned for the current operating conditions. **A move to the next commissioning stage must be authorized.** Testing and acceptance procedures and required state for the next stage e.g. "beam dumping system ready for 43 on 43" etc. have to be defined.

Operation of the LHC will be strongly confined by machine protection issues. Therefore integration of the commissioning for Machine Protection Systems into general beam operation is required, by **close collaboration between machine protection experts and operation / commissioning team**.

The creation of a Machine Protection Coordination Team is proposed. Do we agree that such team would be useful, and what would be the mandate? How could the activities of such team be integrated into operation?

Today, commissioning is mainly discussed in two working groups, LHC-OP and MPWG, both reporting to LTC. The organisation of LHC beam commissioning should be revisited, aiming at an improved integration of machine protection commissioning and general LHC commissioning.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

[1] R.Bailey, Overall commissioning strategy for protons, these proceedings
[2] J.Wenninger, What Systems request a Beam Dump, these proceedings
[3] V.Kain, What is required to safely fill LHC, these proceedings